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Identification of some of the Factors Controlling Aerial Spray Efficacy

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M-X-142

87-01473/

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IDENTIFICATION OF SOME OF THE FACTORS CONTROLLING AERIAL SPRAY EFFICACY

by

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Information Report M-X-142

Canadian Forestry Service

Department of the Environment

1983

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Catalogue no. Fo46-19/142E
ISBN 0-662-12499-5
ISSN 0704-769X

Copies of this report may be obtained from

Maritimes Forest Research Centre
Canadian Forestry Service
P.O. Box 4000
Fredericton, N.B. Canada E3B 5P7

ABSTRACT

A study to identify factors affecting spray efficacy against spruce budworm larvae, Choristoneura fumiferana (Clem.), was conducted in heavily infested stands of balsam fir, Abies balsamea (L.) Mill., and red spruce, Picea rubens Sarg., in and downwind of an operational spray block in New Brunswick in 1981. The effects of two applications of fenitrothion in emulsion formulation were examined to determine trends in larval survival, drop-tray tallies of larval mortality, and cumulative shoot damage. The influences of insecticide deposit rate, of larval development and behavior, and of bud development were considered and compared between the population on fir and the population on spruce. Data on larval survivor densities could not be reliably utilized to calculate spray efficacies because of sampling problems (variance in the sampling universe, accuracy of tallies, and population redistribution within-tree). Moreover the method of assessing deposit (gas chromatographic analysis of foliage) gave only a coarse estimation of deposit distributions across the spray swath. However the use of drop trays to determine larval fallout gave promise of being a sensitive technique for determination of spray efficacy. Tallies from drop trays revealed diurnally-pulsed patterns of larval fallout over several days following spray application. The data suggest hypotheses to explain mechanisms of larval vulnerability and variation in efficacy.

The response of larval populations to spray was measured off-target downwind 400 m and 1200 m. The results suggest that further research on efficacy across an extended swath width should be undertaken.

RESUME

En 1981, on a mené une étude afin de déterminer les facteurs d'efficacité des traitements contre la tordeuse, Choristoneura fumiferana (Clem.), au Nouveau-Brunswick, dans des peuplements de sapin baumier, Abies balsamea (L.) Mill., et d'épinette rouge, Picea rubens Sarg., fortement infestés, à l'intérieur et sous le vent de blocs traités en grand. On a examiné les effets de deux traitements au fénitrothion en émulsion afin de déterminer les tendances de la survie des larves, recenser leur mortalité par le décompte des cadavres tombés des arbres et les dommages cumulatifs causés aux pousses. On a étudié l'influence du dépôt d'insecticide, du développement et du comportement des larves et du développement des bourgeons, en comparant les populations sur les sapins et sur les épinettes. On n'a pas pu se fier aux densités des larves survivantes pour calculer l'efficacité des traitements à cause de problèmes d'échantillonnage (variabilité de l'univers échantillonne, exactitude des recensements de cadavres et redistribution des populations dans les arbres). De plus, la méthode d'évaluation du dépôt (chromatographie en phase gazeuse du feuillage) ne procurait qu'une estimation grossière de la répartition des dépôts sur la largeur de la bande traitée. Toutefois, les plateaux servant à recueillir les cadavres de larves qui tombent des arbres promettent d'être une technique précise de détermination de l'efficacité des traitements. Cette méthode a permis de déceler des variations diurnes de la chute des cadavres pendant plusieurs jours consécutifs au traitement. On peut en tirer des hypothèses pour expliquer les mécanismes de la vulnérabilité des larves et de la variation de l'efficacité.

Le réaction des populations larvaires au traitement a été mesurée hors de la cible, à 400 et à 1200 m sous le vent. Les résultats indiquent qu'il faudrait poursuivre la recherche sur l'efficacité, dans le sens transversal du traitement en bandes larges.

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INTRODUCTION

Aerial application of insecticide formulations is undertaken in New Brunswick to control defoliation of balsam fir, Abies balsamea (L.) Mill., and spruces, Picea spp., by the spruce budworm, Choristoneura fumiferana (Clem.), so as to protect tree growth and reduce tree mortality. While the annual spray program is characteristically successful, operations in individual blocks have variable efficacy. To make progress in reducing the variability and attaining higher cost-effectiveness, it is necessary first to elucidate the biological, physical, and meteorological factors influencing the distribution of spray deposits and the vulnerability of the budworm larvae to lethal contact.

It may surprise readers not familiar with spray technology that the factors bearing upon so well-known a pest as the spruce budworm have not already been fully investigated. However, it is the rule, rather than the exception in international agricultural and forestry crop protection, that spray operators lack information on favorable timing, weather, crop growth, and insect behavior to optimize the effectiveness of spray deposition and toxicity.

Recent research on the atomization process and droplet flight behavior has defined the chain of events encompassing the transport of insecticide from the nozzle of the Grumman TBM spray plane to the conifer leaf (Tomney et al. 1978, Crabbe et al. 1980a, b, 1982, Picot et al. 1980, Picot and Kristmanson 1980). The Teejet nozzle emits a spectrum of droplet sizes varying from <5u to 250u; the numbers median diameter at emission is about 30u, while the volume median diameter is about 95u. The larger droplets tend to settle by gravity near the swath line with a thin deposition pattern on the foliage. The intermediate droplets (30-70u) mostly deposit in the canopy within 300 m of the swath line downwind. The smaller droplets, accounting for about half the number emitted (but only for a tiny fraction of the volume), gradually deposit from swathline to many kilometres downwind. These recent studies of physical and meteorological influences on droplet transport provide a basis for the prospective development of operational methods to optimize the deposition of effective droplets at economical spray rates.

However, before this knowledge can be translated into improved operational methods, it is necessary to identify the target surfaces where impaction of droplets is most effective in reducing larval density. It is necessary also to specify the optimum size for deposition on that target, the density of coverage by droplets to ensure lethality, and larval development and weather patterns favoring maximum vulnerability to contact. Those studies are components of the "biological interface" between spray deposition and larval mortality, as defined by Ekblad et al. (1979). It is postulated that the efficacy of a deposit depends on host tree phenology (development of the bud), the behavioral pattern of each instar, larval response by instar to the weather following spray deposition, and the rate of dissipation of residues.

The continuing objectives of research on the biological interface are to describe the changing target, to identify larval vulnerability, and to quantify the influence of drift. The specific tasks in 1981 were a) to compare contemporaneous spray efficacies on balsam fir and red spruce; b) to define target surfaces in the fir-spruce forest, to examine the implications of spray timing to the phenolcgy of shoot growth; c) to relate mortality to larval development (instar distributions) at the time of spray and to characterize rates of mortality; and d) to relate budworm mortality to various deposit rates in the swath and downwind to 1200 m off-target.

It should be noted that fir and the spruces are about equally important as pulpwood resources in New Brunswick. Sometimes they occur as the fir-spruce mix and sometimes as almost pure stands. Usually a spray block is a mosaic of

various tree species, stand compositions, and age classes. Spray timing has to take account of the early flushing of balsam fir and white spruce, Picea glauca (Moench) Voss, and the later flushing of black spruce, P. mariana Mill. B.S.P., and red spruce, P. rubens Sarg., and the corresponding phenological advancement or retardation of host-specific budworm development. The typical "split-application" regime (two applications) with an interval of several days separating sprays is a safeguard against short periods of low vulnerability by a budworm population on a particular host tree species.

The criterion of effectiveness of a control program is the amount of larval kill, usually expressed as the percent reduction from a third instar (L3) population fix in the midcrown to a pupal population fix (Miller and Kettela 1975). Spray efficacy is derived from a comparison of the population reduction in a sprayed area and an untreated check area; it assumes that the dynamics of natural mortality are the same in each area, and that any difference is due to spray-induced mortality. In the study now presented, spray efficacy refers to larval depopulation of the canopy attributable to lethal or sublethal toxicity.

A second valid criterion of spray efficacy is the amount of foliage saved relative to defoliation in a check plot This measure of success is documented as shoot attack rate and shoot destruction rate.

Spray efficacy should not be confused with spray deposit efficiency, which is independent of biological effect.

This report is a description of survival and mortality of budworm in a stand in an operational block, and in stands outside and downwind of the block. The analysis of data leads to hypotheses on the factors determining efficacy. It is also a test of the methodologies available for measuring larval survival, larval mortality, and spray efficacy.

METHODS

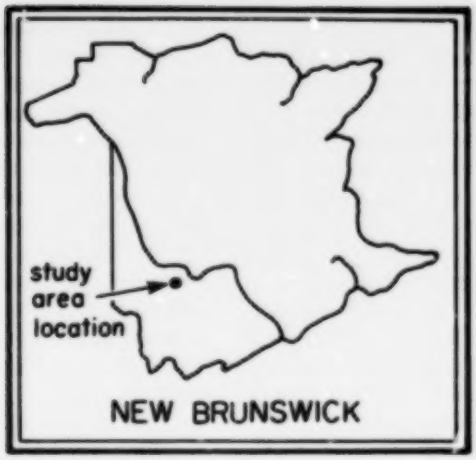
Study Area and Weather Records

The study area was located in southwestern New Brunswick, about 20 km south of Nackawic in an operational block (#95-295) of the spray program conducted by Forest Protection Limited in 1981 (Fig. 1). The general area is a glaciated plain with patches of gravel till supporting fir, red spruce, white pine, Pinus strobus L., and white birch, Betula papyrifera Marsh., and areas of clay with peaty soils supporting higher proportions of black - red spruces.

Three 0.1-ha sample plots were used; a spray plot, 400 m inside the block, a near-field drift plot, 400 m outside the block and downwind, and a far-field drift plot, 1200 m outside the block and downwind (Fig. 1). Each plot consisted of 10 balsam firs and 10 red spruces. Although the spruce will be referred to as red, the hybrid index values (Manley 1971) were in the range of 0.5, which indicated an intermediate introgression of red spruce and black spruce. The term "red spruce" is herein used to distinguish these natural hybrids from characteristic lowland black spruce.

The three stands selected for plot establishment were similar in structure, age class, and composition; they were mixes of fir and red spruce, 30-40 years old, on gravel soils. The spray and near-field drift plots had been spaced within the last two years, so there was good air flow through and around the crowns; the far-field plot had not been spaced and had a denser canopy. The following mean measurements relate to the 60 sample trees, 12 June 1981.

A hygrothermograph in a Stevenson screen in the spray plot provided continuous graphs of temperature and humdity at ground level (1 m). General weather conditions including sunshine records were derived from records of the Fredericton Weather Office (Anon. 1981b). Degree-day heat accumulation was calculated over base 5.56°C from plot charts.



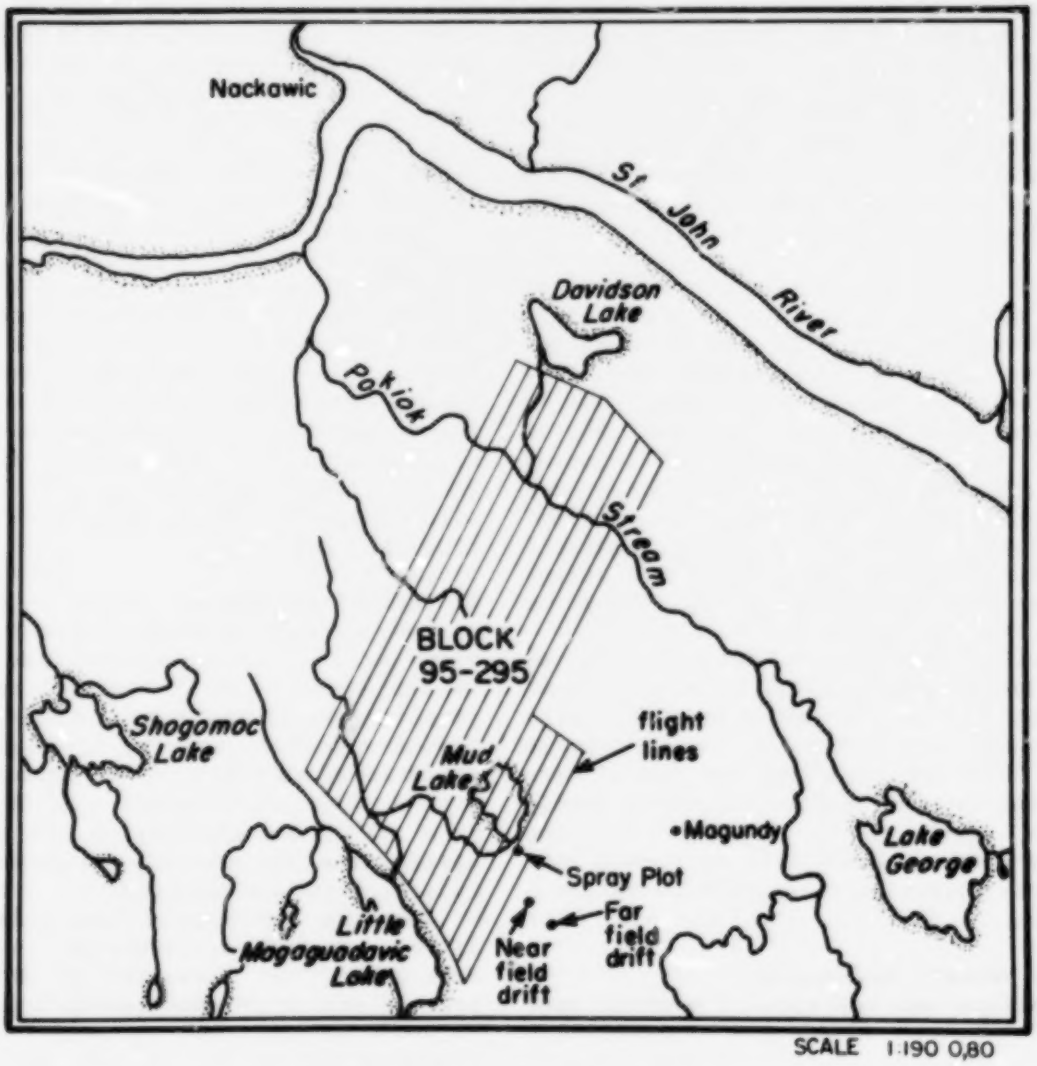


Fig. 1. Location of the study area.

	Fir		
	Spray	Near-field	Far-field
Tree height (m)	10.3	8.5	8.6
Crown height(m)	8.0	6.7	7.1
Crown diam (base)	3.1	3.0	2.7
DBH (cm)	15.0	13.0	11.0

	Spruce		
	Spray	Near-field	Far-field
Tree height (m)	6.9	7.1	7.8
Crown height (m)	5.3	5.5	6.2
Crown diam (base)	2.6	2.6	2.6
DBH (cm)	12.0	11.0	11.0

The spray block was treated with two applications of fenitrothion at a rate of 210 g/ha of active ingredient in 1.46 L/ha of a water-based emulsion. The formulation by volume was 11% fenitrothion, 1.5% Dowanol TPM solvent, 1.5% Atlox 3409 F emulsifier, and 86% brook water. Grumman Avenger TBM aircraft mounting Teejet flat-fan nozzles were used by Forest Protection Ltd. for the spray operation. Three planes flew in echelon, each producing a theoretical swath 134 m wide. The specified flight height above the forest canopy was 30 m.

The first spray application, 0545 h 25 May, took place under a clear sky, a very light westerly wind, and a ground temperature of 0°C. The spray was reported to be "hanging in the air and eventually settling" (indicating extreme stability). That day was warm and sunny, followed by four warm, cloudy, humid but rain-free days.

Similar stable conditions existed at the second application, 0730 h 1 June, except for a stronger wind (8-11 km/h) from the north, and the temperature at 2°C. That day was sunny and fairly warm and the succeeding four days were mostly sunny, warm, and dry (Appendix 1). The 4-day weather after each spray was considered favorable to rapid budworm development.

Spray Deposit Assessment

Foliage was collected 1 h after each spray for spray deposit assessment. One 45-cm branch tip was taken randomly at midcrown from each of the 10 firs and 10 spruces in each plot. All current foliage and the foliage from the previous year were removed and stored in pesticide-grade ethyl acetate in a freezer, prior to analysis by gas chromatography.

To determine degradation rate, samples from both hosts were collected 2 days after the first application, and 2 and 4 days after the second application. Each sample was a composite (shoots from all 10 trees); samples were collected for both hosts in all plots.

GC analysis is one of the less frequently used methods of deposit assessment. The alternative methods were considered inappropriate or impracticable for this experiment; Kromekote cards or glass plates are poor collectors of the fine droplets expected in drift plots, while tracer dye additives were not feasible in this operational spray.

Chemical analysis of foliage had the advantage that it measured the insecticide directly, not involving the specific degradation problem associated with use of tracers. It had the disadvantage that it provided values only for large sample units (the branch tip) and the high cost of analysis precluded more intensive sampling. No attempt was made to size the droplets, or to identify within-crown or within-branch distribution patterns.

Biological Assessment

The aim of sampling larval populations was to characterize the densities in the stands and to compare trends in response to varying insecticide dosages. It was expected that the far-field plot would serve as the untreated check plot, but, in fact, it received a faint dosage from the first application and a light dosage from the second, and an insecticidal effect was elicited.

Sampling for budworm population densities, instar distribution, and bud development was conducted at intervals from 18 May to 24 June (every 2-3 days).

This span of sampling included all larval stadia from second to sixth. Samples were collected on 16 days, including successive collection for 3 days after each spray application. At each sampling, one 45-cm branch tip was pole-pruned from the midcrown of each of the 10 firs and 10 spruces in each plot. The midcrown branch sample unit was used instead of the more intensive 4-level sampling representing the whole crown (described by Morris 1955), because a larger number of trees could be covered with the available manpower. This sampling procedure would account for more of the variability because the major source of variance occurs at the intertree level when determining plot means (Morris 1955).

Larval populations and spray efficacy At each sampling, the live and dead larvae were counted on the 45-cm branch tips. Only the numbers live were used to plot survivor trends. Branch surface area was calculated as length x average width. Numbers of shoots per branch were determined by counting all buds early in the season; later by counting the number of flushing shoots. Thus each branch produced three measures of larval density: per square metre of branch area, per 45-cm branch, and per 1000 shoots.

The procedure was to carry the branches individually in plastic bags to the laboratory, where they were examined immediately (or after storage overnight in a cold room) by a crew of six to eight searchers (summer student employees). Each branch was cut into small portions for the search by naked eye for exposed larvae and for evidence of larval habitats (silk, mined needles, frass). Such habitats were opened to ascertain the presence or absence of larvae. No formal iterative check on once-examined foliage to determine searching error was instituted, on the assumption that it was more efficient to process many branches with an unknown measurement error, than to process fewer branches with a known error.

The intention was to use data on population survival to derive estimates of spray efficacy (percentage population reduction) in the conventional way (Abbott's Method 1925). The percentage population reduction across a given period would be calculated from prespray and postspray densities in each plot. On the assumption that at 1200 m downwind of the block the deposition and influence of insecticide would be negligible, it was expected that the far-field plot would serve as a control or baseline for the rate of natural population reduction. Therefore, spray efficacy in the spray plot and the near-field plot, after each application could be derived from Abbott's formula.

Larval development The first 10 live larvae (or fewer as available) encountered on each branch tip were measured (head capsule and body length) to determine instar distribution (Anon. 1981a) and for calculation of larval index values (Hardy et al. 1977).

Bud development New shoot phenology was recorded by periodic sampling of bud or shoot lengths, from base to apex, from the fir and spruce branches routinely collected in three plots, using a sample of the first 20 buds counted on each branch tip.

Larval mortality In addition to the comparison of prespray and postspray survivor population densities, the fallout of larvae to drop trays was tallied as a measure of spray-induced mortality. A 1.7-m^2 (18-sq ft) drop tray was randomly placed under the crown of each sampling tree. To avoid disturbing the crown above each drop tray, branch sampling for larval survivor populations was restricted to the side of the crown opposite to the drop tray. On the two spray days, five counts of larval fallout were made at approximately 3-h intervals beginning about 2 h after spraying. For the first spray, three counts were made the following day, in the morning, noon, and midafternoon. This was followed by two counts, morning and midafternoon, for 5 days after spraying. For the second spray, the three counts

were made for 4 days after spraying, while the fifth day had only the morning and midafternoon counts.

It was recognized that larval fallout had two components: toxic effect of the spray, and spin-down associated with natural stresses such as food shortage and disturbance. However, it was known from earlier studies of drop-tray methodology that natural fallout by L3-L5 is ordinarily very light.

Lethality in larval fallout To determine the proportion of falling larvae which had contacted a lethal dose of insecticide, samples of newly-fallen vigorous larvae were collected at intervals from drop trays under fir and spruce in all plots. These larvae were transferred in the field to creamer cups (maximum 5 larvae per cup) containing the McMorran diet. The creamers were held at ambient shade temperatures in the insectary for 48 h, when larvae were tallied as apparently healthy, moribund, dead, or missing.

Defoliation Assessment

The rate of feeding damage was assessed by periodic measures of rates of shoot attack (feeding damage present or absent) and shoot destruction (axil destroyed), and by one (31 July) estimate of defoliation (percent needles removed). Shoot attack and shoot destruction rates were routinely measured on each sample branch tip brought in for larval population assessment throughout the study period.

The defoliation estimate was conducted by the modified Fettes method, whereby all 60 study trees were sampled. Two 45-cm branch tips were taken at random at midcrown from each tree. The current defoliation was estimated using the following categories:

1	nil defoliation
2	1-25% needles removed
3	26-50% needles removed
4	51-75% needles removed
5	76-100% needles removed (shoot axil intact)
6	Shoot needles and axil completely destroyed

The two branches were combined and the number of shoots in each category was determined. A tree defoliation index was calculated by the same method as the larval development index (Hardy et al. 1977). An average plot value was calculated and was then converted to a percent defoliation estimate for each species, in each plot.

RESULTS AND DISCUSSION

Larval mortality is determined by the dosage and within-stand distribution pattern of insecticide deposit, the receptivity of the target foliage (shoot development), and larval behavior-induced vulnerability to toxic contact. Definition of these factors and their interaction is needed to explain variation in the efficacy of spray operations.

Insecticide Deposit

The method chosen for characterization of fenitrothion deposit in the three plots was GC analysis of branch-tip samples of foliage from fir and red spruce. The mean concentrations (Table 1, Appendix II) show similar rates of deposition in the spray plot for both species and both applications, about 1 ppm. It is conjectured that these rates are low but within the norms of successful operational delivery, although the literature contains few fenitrothion field estimates (Yule and Duffy 1971, Yule and Varty 1975, Sundaram pers. comm. 1982[2]).

In the near-field plot, at least 400 m downwind of the spray block, deposits from the first application were unexpectedly low on both host species, perhaps by an order of magnitude, but the cause is unknown. Drift deposits from the second application were unexpectedly high - readings as high as or higher than in the spray plot itself - whereas concentrations around 80-90% lower might

[2]Sundaram, K.M.S. Research Scientist, Forest Pest Management Institute, Canadian Forestry Service, Sault Ste. Marie, Ont.

Table 1. Mean deposit of fenitrothion ± standard deviation in each plot for the first and second applications

Application	Mean deposit of fenitrothion mg/kg* foliage Plots					
	Spray		Near-field drift		Far-field drift	
	balsam fir	red spruce	balsam fir	red spruce	balsam fir	red spruce
First	1.41±0.35	1.77±0.88	0.04±0.03	0.02±0.03	0.08±0.19	0.05±0.06
Second	1.15±1.11	0.90±0.60	1.25±0.68	1.34±0.51	0.55±0.54	0.84±1.17

*Foliage was not oven-dried.

be expected on the basis of the Crabbe et al. experiment (1982).

Similarly in the far-field plot, 1200 m downwind of the block perimeter, deposit was negligible from the first spray application, and substantial from the second. On both days, wind orientations and meteorological conditions were apparently favorable in conventional terms for passage of the drift cloud over the plots.

The weakness of this characterization of the dosage received in the three plots is that the sample size - 10 branch tips per species per plot - is small in relation to the sampling universe. Within this single midcrown layer of the canopy (which holds most of the budworm larvae) the standard deviations associated with the data indicate high but inconsistent variability. The single branch as a sampling unit appears to be subject to much deposit variation, probably as a result of filtering of droplet flow through the canopy.

A further weakness is the lack of any information on droplet size and coverage of budworm habitats. It is assumed that most of the impacted droplets in the near-field and far-field drift plots were medium to small, < 40u, on the basis of experimentation conducted earlier by Picot and Kristmanson (1980). Thus it is conjectured that target coverage in all three plots was substantial in the second application. These small droplets are the most likely to reach sheltered surfaces in the larval habitat.

Nature of the Target

The insecticide target is the budworm larva and its microhabitat, that is, any exposed surface where the larvae walk, spin, feed, or deposit frass within the few days before the fenitrothion dissipates or degrades to non-toxic levels. Sampling showed that insecticide residues had decreased at least 70% by the third day. The budworm microhabitat is a dynamic target, constantly changing as buds swell and new shoots flush, and as budworm change feeding sites and spin their defensive webbing on old and new leaves.

Growth and behavior of the larvae are related to shoot development; however, bud flushing phenologies were different for balsam fir and red spruce (Fig. 2). Because shoot and larval developments were similar in the three plots the data were combined. Bud growth took place earlier on fir than on red spruce; for example, fir buds had elongated to 10 mm by 22 May, spruce buds not until 4 June. Larval development was also more advanced on fir than on spruce, but less markedly so; L4 peaked on fir by 28 May, on spruce by 1 June. Thus on the spray days larvae and buds on fir presented a different target for droplet impaction than on spruce. By the end of the larval

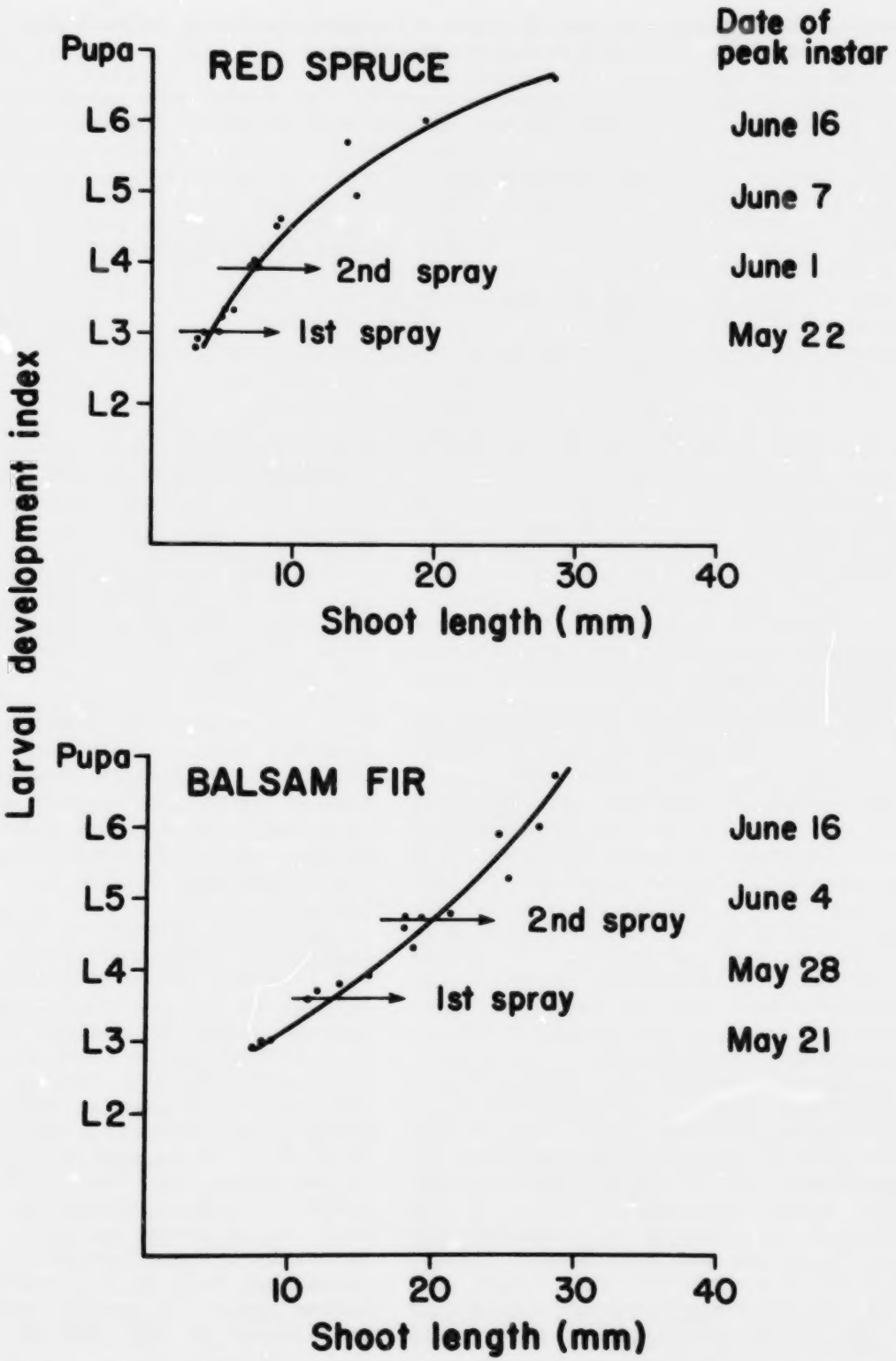


Fig. 2. Larval and shoot development on balsam fir and red spruce.

stage, instar distributions on balsam fir and red spruce had become similar, with peak L6 occurring in both species on 16 June and shoot length becoming similar by 24 June. Synchrony of shoot and larval developments may change with varying weather conditions. Kettela (pers. comm. 1982)[3] has observed that cool wet springs may slow larval development while shoot development proceeds vigorously. Heavy flowering years may promote faster larval development (mean instar) on flowering branches (Bess 1946, Blais and Thorsteinson 1948).

Survivor Population Trends in Relation to Spray Efficacy

The plan was to use data on larval density in the crowns, comparing prespray and postspray values, to graphically show population reduction across the spray treatment period, and to derive estimates of spray efficacy.

The first problem was to examine the merits of the three bases for representation of density: per square metre branch area, per 45 cm tip, or per 1000 shoots. Substantial differences in their graphic representation were seen. The estimates per 1000 shoots were desirable because the shoot is a unit of budworm habitat, but were rejected because shoot counts were not stable throughout the sampling period. Early in the season, all buds were counted because it is impossible to tell which are viable and which are not. But not all buds become shoots; some abort for unknown reasons and some are killed by frost. Thus the number of living shoots on a branch diminishes as the growing season advances. In effect, if the absolute population of larvae stayed constant the density per 1000 shoots would be shown as a seasonal rise. Thus calculations of density on the shoot basis tend to underestimate the densities of L2 and L3 relative to the densities of L4 and L5. For this reason, the measure per 1000 shoots was discarded.

[3]Kettela, E.G. Forestry Officer, Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, N.B.

The graphs of population per square metre and per 45-cm branch tip are similar. However, the actual size of branches varied according to shape, so it is considered that there is considerable variance in data based on single branch units. Therefore that measure of density is not further reported.

In this report, the basis for measurement of density is the square metre branch area. This basis also has its artifact, in that branches grow during the season, therefore the tendency is for later values to be relative underestimates compared with early season values.

The population trends per square metre in the three plots, for fir and for spruce, are compared in Fig. 3. Several sampling problems were encountered in the attempt to establish reliable estimates of density: a) variance among branches, crown levels, and trees, b) searcher error, especially underestimation of L2 and L3, and c) redistribution of populations among crown levels.

Variance in branch populations resulted in the unpatterned zig-zag in density, from sample day to sample day (Fig. 3). However, such scatter is not too important when evened-out by frequent sample days.

The most troublesome problem is the suspected underestimation of densities of early instars (May). It is more difficult to locate L2 and L3 on sample branches in mid May than L5 or L6 in mid June. It is probable that a large proportion of small larvae might be overlooked, while tallies of large larvae are likely to be accurate. This difficulty of search might explain the apparent slow rate of population decline between 18 May and 1 June, particularly on spruce (Fig. 3). Natural reductions in density between the L3/L4 stage and the pupal stage ordinarily run 65-90% on fir and spruce (Morris 1963, Kettela et al. 1977, Hardy and Gagnon 1981), which is much greater than the apparent declines plotted in Fig. 3. If this is so, then the usefulness of such estimates of population reduction by insecticide is questionable.

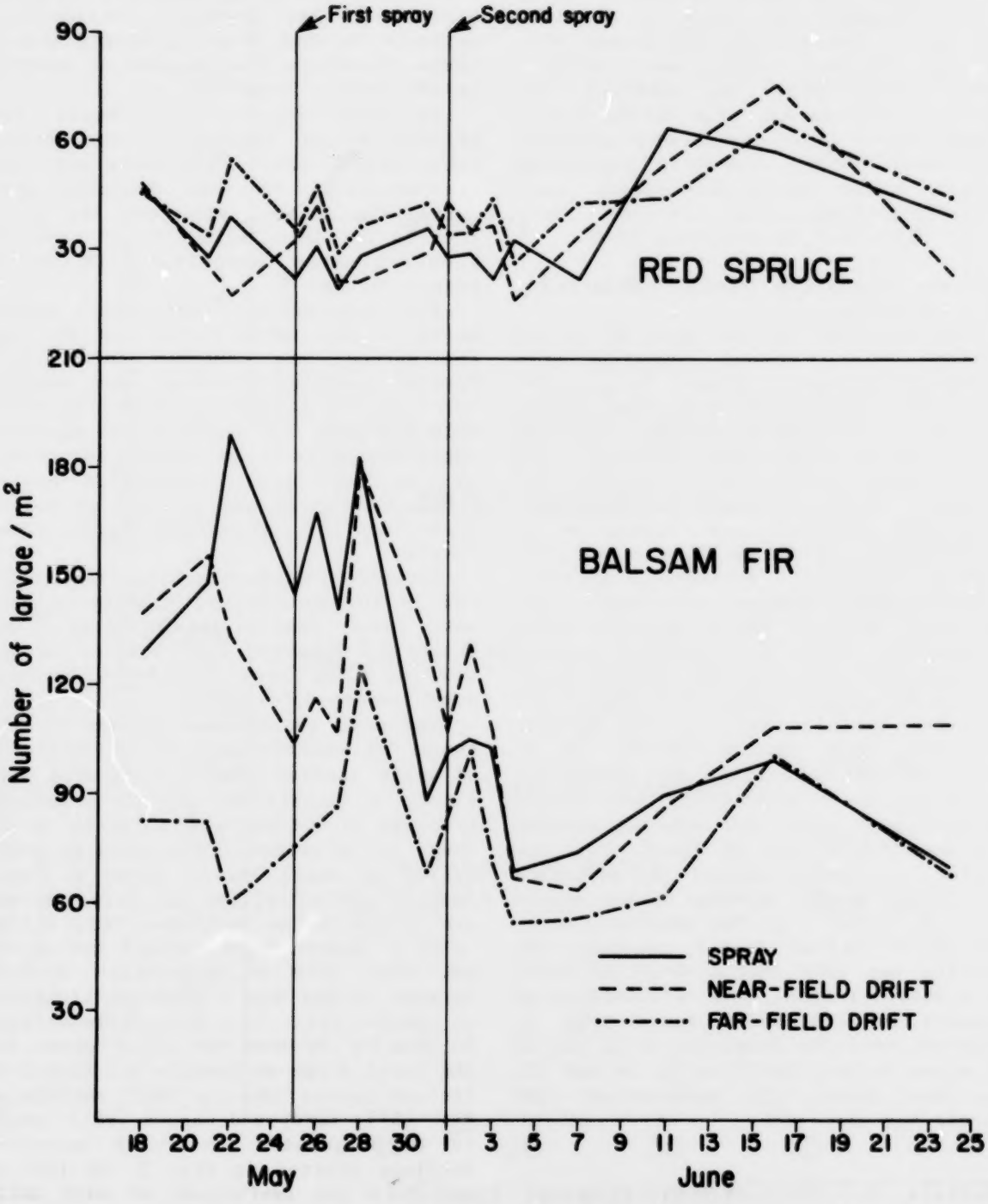


Fig. 3. Midcrown larval population trends on balsam fir and red spruce.

Real fluctuations in population density in the midcrown may also result from redistribution among crown levels. The population graphs (Fig. 3) suggest a strong possibility of within-crown redistributions after the second application. A synchronization of peaks and troughs occurred for fir in all plots on the several days following spray. Fir buds at that time were well flushed and budworm relatively exposed (unlike spruce buds), and there was much sublethal knockdown. It is hypothesized that the apparent increase in density on 2 June, the day after spray, may have resulted from recruitment of upper crown larvae stimulated to spin down to the midcrown level. Indeed, some larvae, which had spun down on spray day, were seen attempting to re-establish on lower branches. Nevertheless, population density in the midcrown was not sustained by any such recruitment (Fig. 3).

Another rise, synchronized in all plots and in both species, occurred at peak L6 (Fig. 3), about 2 weeks after the second spray. This rise was gradual and sustained, and took place too long after spray day to be insecticide-induced. It is postulated that this recruitment to midcrown may be due to natural fallout of mature larvae in the upper crown, probably by weather disturbance as wind or rain. It is believed that the cause was not food depletion because the same rise occurred on both hosts, although fir was heavily defoliated and spruce lightly so. Morris (1963) reported among-level redistribution only as the result of food depletion.

There is a possibility that those unexpectedly high values of L6 density may have been an underestimate. Mature larvae easily dislodge when sample branches are being clipped by pole-pruners, and are thus lost from the population tally. Churcher (1982) suggested that the underestimate may be as high as 40% on fir, while on spruce, he believed, L6 was insensitive to disturbance.

These sources of error cast doubt on the reliability of the survivor density measurements presented in Fig. 3, or even on the general use of survivor populations for estimates of spray efficacy in high forest.

Evidently the population changes induced by insecticide occurred mainly in the 4 to 6 days following each spray. Because the population density was unstable from 26 May to 4 June, efficacy estimates to compare first and second sprays were considered too unreliable and are not presented. However, it is possible to derive a value of efficacy for the whole double application regime for fir, with the "corrected mortality" resulting from insecticide treatment (Abbott's formula 1925).

	Mean larval densities/m^2 fir foliage	
Plot	May 20-25	June 6-11
Spray	161	83
Near-field	131	73
Far-field	73	59

	Percent	
Plot	Reduction	Corrected mortality
Spray	48	36
Near-field	44	31
Far-field	19	

However, this corrected mortality is believed to be low because there was a small insecticidal effect in the far-field plot. Even so, two-spray efficacy on fir was low in the spray plot, and even lower in the near-field drift plot. The data used in Fig. 3 do not indicate any measurable efficacy on spruce.

Relationship of Efficacy to Insecticide Deposit

Although reliable measures of efficacy were not obtainable because of inaccurate prespray tallies, trends of larval density reduction were broadly correlated with insecticide deposit rates. After the first application, the deposit of insecticide in the spray plot

(Table 1) was associated with a decrease in density of survivors on fir but not evidently on spruce (Fig. 3). Nevertheless it produced substantial fallout of larvae from both fir and spruce, at about equal proportions relative to the unequal densities in the host crowns (Fig. 4). Evidently the fact that the population on fir was phenologically advanced (40% L3, 59% L4) compared with the population on spruce (90% L3) did not influence relative vulnerability on this occasion.

In the near-field and far-field plots where only a trace of insecticide was deposited during the first application, only a trace of response in terms of larval fallout is evident (Fig. 4), scarcely above the expected background fallout in the absence of chemical intervention.

The second application produced a similar concentration of deposit on the spray plot, and unexpectedly high concentrations downwind in the near-field and far-field plots, where the presumably smaller mean droplet size should have resulted in good coverage (Table 1). Decreases in survivor density were detectable on fir on all three plots, but not on spruce (Fig. 3). The drop-tray tallies were much higher on balsam fir than on red spruce in all three plots. Taking account of the populations in the fir crowns compared with spruce just before spray, it is calculated that the application was eight times more efficaceous on fir than on spruce in the spray plot, more than three times as efficaceous in the near-field plot, and almost twice as efficaceous in the far-field plot (Fig. 4). This higher vulnerability of the populations on fir may be related to advanced larval and shoot developments as discussed in the next section.

It is possible, but difficult, to use drop tray tallies as a measure of efficacy by calculating the percent fallout. The problem is to measure the total larval population in the vertical column of canopy above the drop tray. The mean crown size of fir in the spray plot was 8 m high and 3.1 m diameter at base. Assuming from sampling that this average tree incorporates about 25 m branch surface, then the average population per fir tree may have been about 25 x 100 = 2500 at the time of second application. Since the drop tray (1.7 m^2) represents about one-quarter of the fallout zone from each fir in the spray plot, it is estimated that the number of budworm in the crown column over the tray averaged about 600. The average total collection per drop tray in the seven days following second application was 218 for firs in the spray plot, 108 in the near-field plot, and 34 in the far-field plot. Thus the estimated insecticidal reductions in the population on fir were about 35% in the spray plot, 18% in the near-field plot, and 7% in the far-field plot. Admittedly these calculations are crude estimates based on untested assumptions, but they confirm the survivor assessment and defoliation estimates that, in operational terms, the spray effect in the sampled location was unsatisfactory and off-target drift was substantial. From the experimental point of view, of course, the success or failure of the operation in this one block was of no consequence.

In summary, the significance of this comparison of larval populations and deposit is that (1) mortality of larvae is broadly related to insecticide deposit rate, but there are host-specific deviations from the correlation, (2) the use of surviving populations as a measure of response to insecticide may be unreliable because of various kinds of sampling error, (3) drop-tray counts are a sensitive way of detecting insecticide intervention by overhead and drifted sprays, but calculation of a reliable percent efficacy requires costly crown measurements, and (4) drift may have substantial influence on budworm populations more than 400 m downwind; this suggests that effects of swath width and application frequency would be appropriate research fields.

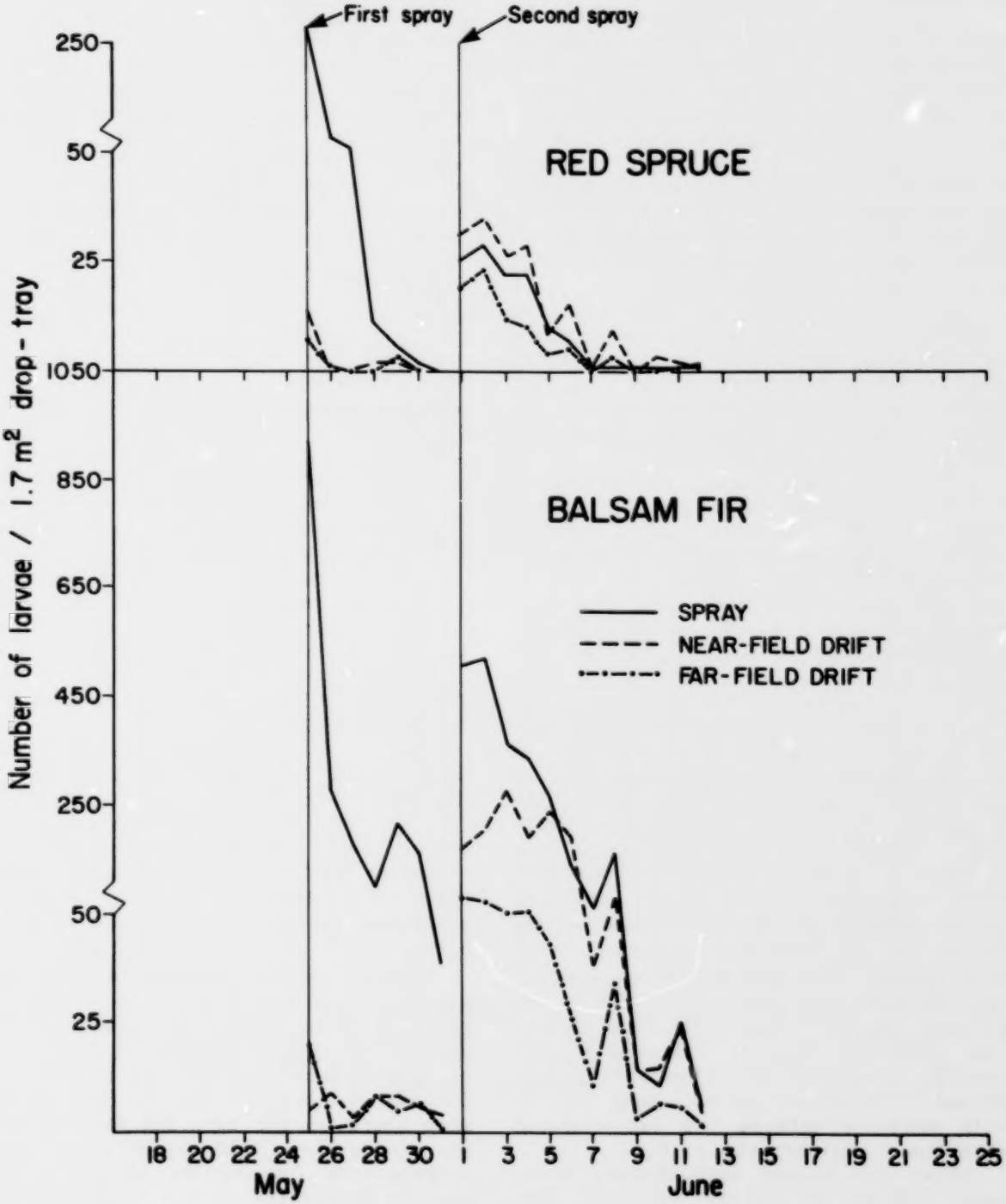


Fig. 4. Drop-tray counts per day from balsam fir and red spruce.

Relationship of Efficacy to Larval Behavior and Development and to Bud Development

Spray efficacy (larval mortality) is influenced by several factors: a) larval susceptibility by instar; that is, the rule that larger individuals (later instars) generally require a larger dose to produce a given population mortality; b) behavioral vulnerability, or the probability of lethal contact as induced by weather-related patterns of movement or feeding; and c) bud type and growth affecting larval shelter, locomotion, and feeding.

Observations on the asynchronized instar distributions on fir and spruce, on the phenological gap in bud development of these two hosts, and on the differences in responses as measured by fallout, lead to various hypotheses to explain variation in efficacy.

After the first spray application, a fallout of larvae from fir and spruce occurred in the spray plot (which received the only appreciable spray deposit). On fir the larvae were late L3 and L4, mining buds that were beginning to flush (Fig. 2). On spruce, larval development was at peak L3; as yet bud mining was rarely occurring and the buds were just beginning to elongate (Fig. 2). Most larvae on spruce were enclosed in a needle mine or in a silk sheath within a cluster of mined needles. It is postulated that on both host trees, the exposure to the insecticide occurred when larvae were moving outside the protective mine or silk tube. On fir, exposure may have occurred with movement to the outside of the bud to web needles to the bud, to form silk defences, or to expel frass. On red spruce the contact may have occurred more frequently in the movement toward the buds from webbed leaf clusters, and in spinning a silk shelter along the slowly expanding bud. L2 and L3 on spruce spend a long time in silk shelters outside the bud compared with their counterparts on fir.

After the second application, abundant fallout of larvae occurred from balsam fir, but only weak fallout from red spruce (Fig. 4), as already discussed. Two hypotheses to explain the greater vulnerability of the fir population are a) greater deposit of insecticide on the active habitat surfaces on fir (the 15-20-cm flushing bud) in spite of the GC evidence of equal deposition on fir and spruce branches, and b) behavioral differences because the fir population was further developed than the spruce population by almost one instar (Fig. 2). Larvae on fir between 1 June (26% L4, 73% L5) and 4 June (20% L4, 58% L5, 14% L6) were occasionally observed to be feeding on expanding leaf tips and spinning feeding tubes between adjacent buds (i.e., exposure in the outer habitat). However, the spruce-dwelling population (1 June: 26% L3, 53% L4, 21% L5, 4 June: 50% L4, 44% L5) was more confined to the mine within the slightly elongated bud (i.e., little exposure in the outer habitat during the first few days after insecticide deposit). Thus larval behavior (especially L4) and the corresponding development of the bud may strongly influence the efficacy of a spray applied at conventional dates. Activities of critical importance may be silk spinning and removal of frass, if they result in movement in the outer habitat.

After budbreak (first visibility of naked green leaves in the new shoot), the bud scale quickly disintegrated on fir, and was held a little longer on red spruce, but in neither species was it an important shelter against droplet deposition on foliage, in contrast with the prolonged retention of the cap on white spruce.

Support for the hypothesis that temperature affects larval behavior is given in Figs. 5 and 6. Counts of the numbers of larvae falling to drop trays at intervals across the day showed that the highest rate of fallout was in the warm hours of the day. The diurnal peak was around noon. This suggests that high temperatures induced the larvae to engage in activities in the outer habitat,

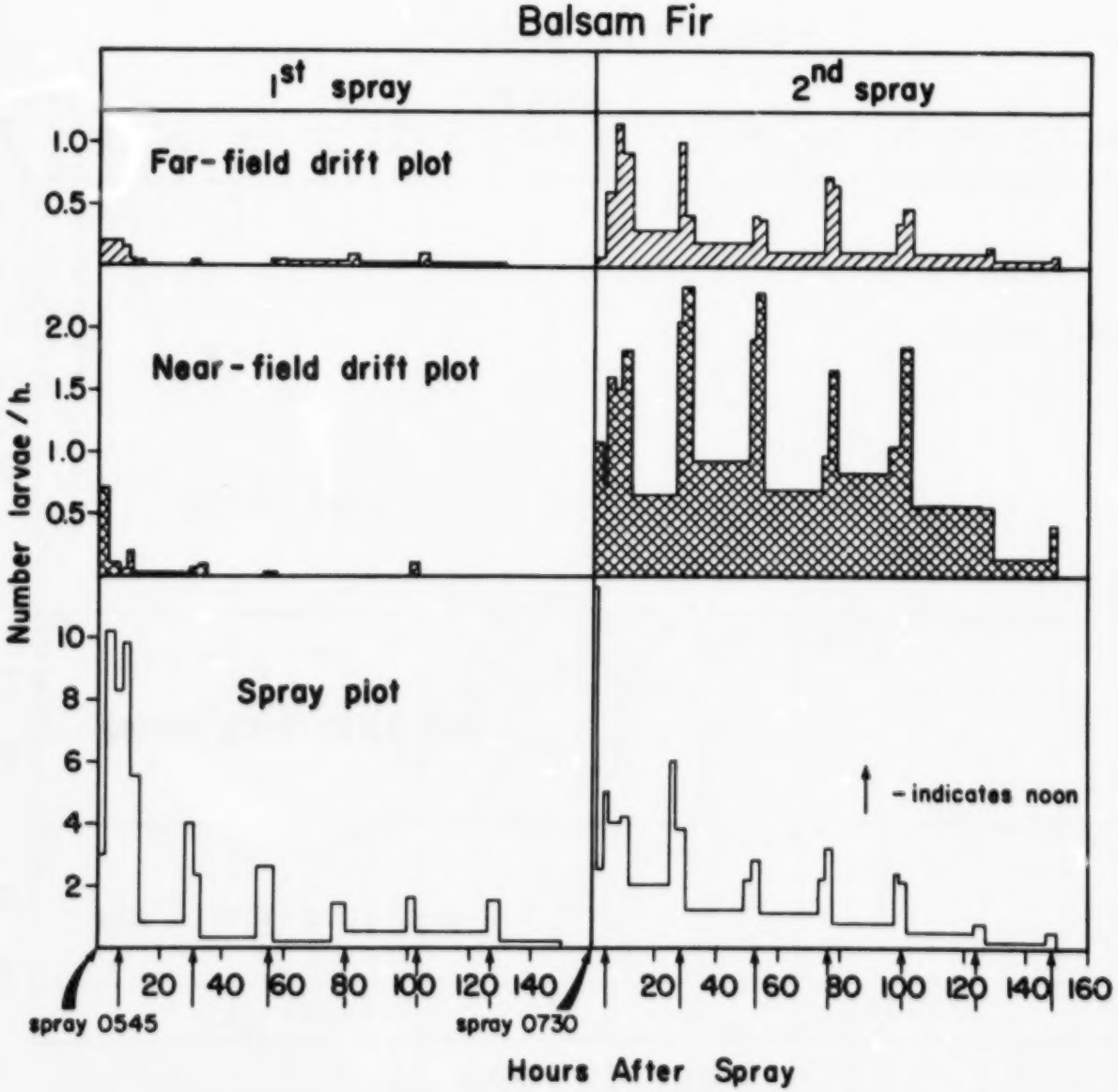


Fig. 5. Periodic drop-tray counts throughout the day - balsam fir.

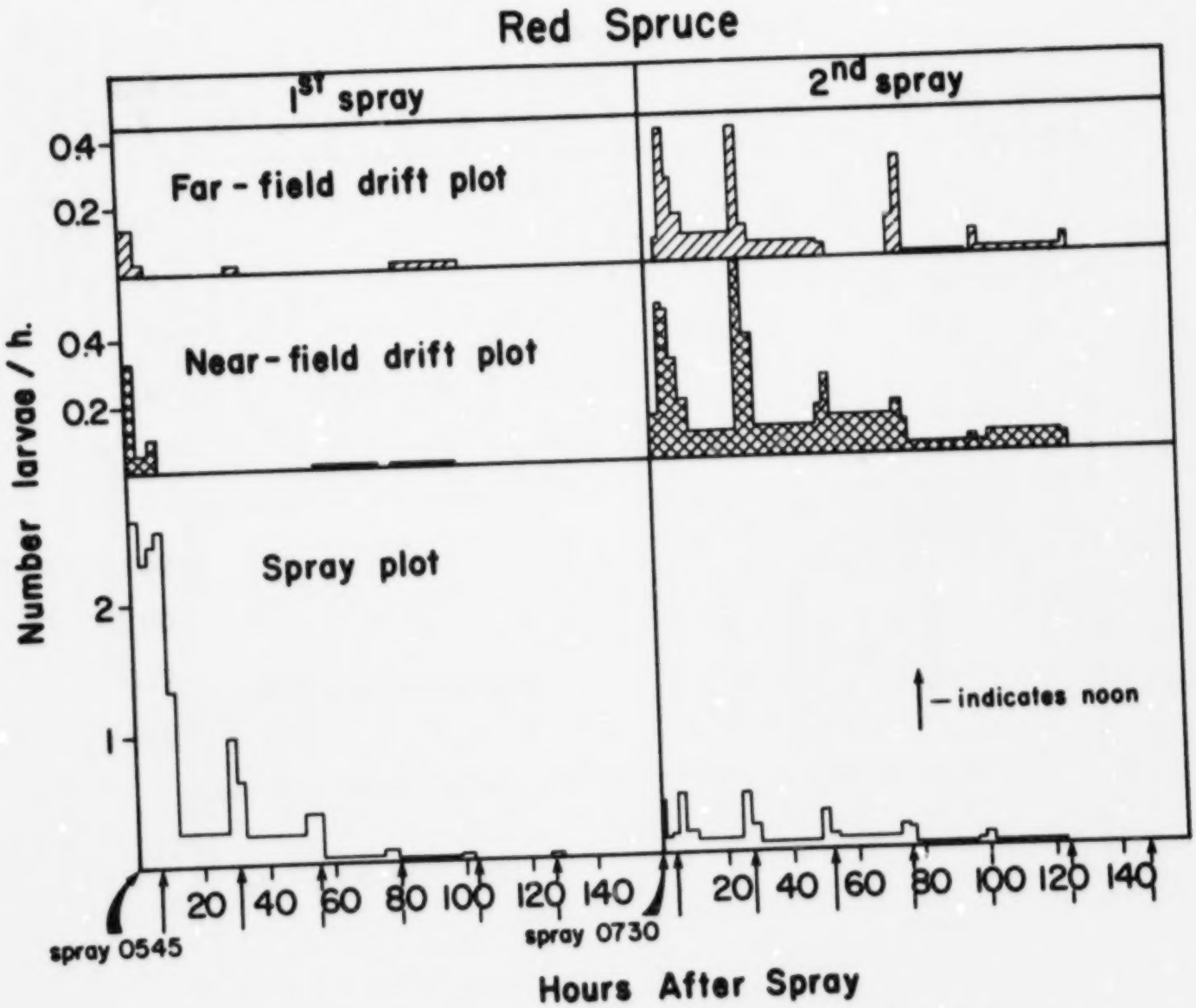


Fig. 6. Periodic drop-tray counts throughout the day - red spruce.

where insecticide droplets had impacted and that the main pathway to toxicity is dermal contact by smear from residues.

Mortality peaked in the first 2 days and diminished to background levels within 7 days. Analysis of foliage showed rapid diminution of residues (by 70% after 2 days), and Nigam (1975) has shown a halving of contact efficacy from fenitrothion residues aged 5 days. Possibly the final mortalities may have resulted largely from feeding on young leaf tips bearing adsorbed deposits.

The diurnal pattern of larval fallout from spruce was similar to that on fir, though at much lower rates. This same pattern was observed in all three plots after the second application (Fig. 5). However, the drop-tray tallies from spruce showed no correlation between deposit and fallout in the three plots.

Note that few larvae fell to drop trays in the first 2 h (cool early morning) after spray application. After the first application, only 140 larvae fell within that period, compared with 1201 collected from 10 fir and 10 spruce drop trays during the first day in the spray plot. After the second application, the corresponding values were 120 and 529. Therefore, it is inferred that only a small percentage of larvae may be directly hit by an impacting droplet. Mostly, larvae have to move from the shelter of their silk-lined tubes to a receptor surface in the outer habitat before they can acquire a lethal dose.

The alternative hypothesis is that the fallout larvae receive a toxic dose by direct impingement of droplets during the 20 min persistence of the aerosol cloud in the block, but that the expression of that toxicity may be delayed up to 6 or 8 h depending on the dosage. That hypothesis is rejected because fallout on successive days is pulsed to the warm hours of the afternoon.

Table 2 compares daily instar distributions in the drop-tray collections and in the crown populations in the spray plot on several days. It is evident that after the first application there was a much bigger proportion of L2 in the drop trays than in the crowns of fir and spruce. Evidently the L2 were more prone to insecticidal knockdown than the L3 and L4. It is suggested that the L2 were more vulnerable i.e., more exposed to contact at spray time. The other alternative, that L2 are more susceptible than later instars, is rejected because of evidence by Nigam (pers. comm. 1977)[1] who found that laboratory-sprayed L2 were more tolerant to fenitrothion than L3 and L5. There is no evidence from the Magundy experiment that the spray discriminated between L3 and L4.

The second application produced conflicting results on days 1 and 2 (Table 2: data for fir only). Since those days produced about equal drop-tray catches, and thus carry equal weight as evidence, it is concluded that the spray did not discriminate among L3, L4, and L5 components on fir. The fallout from spruce after the second application was too light to justify instar analysis.

The inference from these data is that L2 may be relatively easy to kill at the time when they are moving from leaf-mining status to bud-mining status, but that bud mining L3, L4, and L5 are targets of similar vulnerability on the fir host.

The influence of cold or wet weather in the several days immediately after spray application remains untested. It is speculated that adverse weather would inhibit larval movement, and therefore reduce vulnerability. Rain might elute residues to run-off, thereby reducing exposure.

[1]Nigam, C.P. Research Scientist, Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, N.B.

Table 2. Comparison of percent distributions of instars in budworm populations in midcrown branches and drop trays, from balsam fir and red spruce, in the spray plot on spray day and the following day

	L2	L3	L4	L5	No. in sample
		%			
May 25 Fir					
Drop tray	7.6	32.3	60.0		774
Crown	0.5	40.4	59.1		183
May 25 Spruce					
Drop tray	28.2	64.9	6.9		205
Crown	2.6	89.7	7.7		39
May 26 Fir					
Drop tray	10.6	26.4	63.0		235
Crown	0	28.1	71.9		146
May 26 Spruce					
Drop tray	37.3	39.2	23.5		51
Crown	0	75.0	25.0		44
June 1 Fir					
Drop tray	0	4.9	33.9	60.9	263
Crown	0	0.8	26.0	73.2	131
June 2 Fir					
Drop tray		1.3	19.8	78.9	374
Crown		4.8	25.4	69.8	126

Lethality in Larval Fallout

Larvae falling from the crown to the drop tray may be lethally intoxicated, sublethally affected, or unaffected. The percent survival of newly fallen larvae, collected alive at intervals during the first 2 days (spray and the next) of each application and reared on diet for 48 h (Table 3) was as follows

Application	Spray plot	Near-field	Far-field
		%	
Fir			
First	10	*	*
Second	21	17	49
Spruce			
First	6	*	*
Second	42	29	36

* Too few data.

Thus most larvae falling in the spray plot after moderate deposits from the first application (Table 1) had received a lethal dose. However the somewhat lighter deposits from the second application, producing moderate fallout of larvae from fir and light fallout from spruce in all plots (Fig. 4), permitted much higher viability in larvae collected from drop trays. It is speculated that sublethal exposure, perhaps by small droplets, may contribute to the efficacy of insecticide treatment, especially in the swath extension.

In contrast with the low viability of fallen larvae, budworm collected from branches on the same days had a much higher survival rate to 48 h on diet (Table 3), summarized as follows in percentages:

Table 3. Survival of diet-reared (48 h) spruce budworm larvae collected from drop-trays and crowns of fir and spruce on spray day and the following day

Date	Plot	Fir				Spruce			
		Drop trays		Branches		Drop trays		Branches	
		No. coll.	No. surv.	No. coll.	No. surv.	No. coll.	No. surv.	No. coll.	No. surv.
May 25	Spray	115	13	87	45	75	6	35	14
26		55	4	87	60	24	0	14	10
Total		170	17	174	105	99	6	49	24
June 1	Spray	218	36	81	57	12	5	24	15
2		142	31	96	74	7	3	31	18
Total		360	67	177	131	19	8	55	33
May 25	Near-field	1	1	92	49	3	3	29	11
26		2	2	86	55	0	0	35	24
Total		3	3	178	104	3	3	64	35
June 1	Near-field	61	8	79	56	14	2	27	16
2		48	11	88	72	13	6	25	14
Total		109	19	167	128	27	8	52	30
May 25	Far-field	2	1	62	35	1	0	34	11
26		1	1	65	41	0	0	37	24
Total		3	2	127	76	1	0	71	35
June 1	Far-field	31	12	73	50	13	3	30	22
2		18	12	73	67	9	5	28	20
Total		49	24	146	117	22	8	58	42

Application	Spray plot	Near-field	Far-field
		%	
Fir			
First	60	58	60
Second	74	77	80
Spruce			
First	49	55	49
	60	58	72

Mortality of larvae collected from branches had two main components, handling injuries and insecticide absorption. It is inferred that little mortality was insecticide-induced, because survival of budworm in the canopy was fairly uniform (Table 3), regardless of respective deposit values for each plot. Therefore, populations which survive on branches are those which have not yet been exposed to insecticide contact. It is further inferred that once the larva is exposed to the toxic dose of insecticide it does not usually linger in its habitat. This was confirmed by the small percentage of dead larvae found in the mines or tubes after spray.

The numbers of larvae, alive or dead in the branch at counting time, summed over the 16 sample days, were

	Fir	Spruce
Spray plot		
Live	2229	613
Dead	334	96
Dead %	13	14
Near-field		
Live	2306	602
Dead	119	60
Dead %	8	9
Far-field		
Live	1624	7474
Dead	88	64
Dead %	5	8

Defoliation in Relation to Larval Populations and Instar

Because of the low success of the operation in the experimental area of the spray block, larval populations still remained in the range of 70/m² on balsam fir and 30/m² on red spruce a week after the second application (Fig. 3) with little difference among plots. The shoot attack rates (Fig. 7) and shoot destruction rates (Fig. 8) show the defoliation effect of these survivor populations. In balsam fir, the final accumulations of shoot attack and shoot destruction were highest in the near-field drift plot but the spray and far-field drift plots had similar survivor populations and defoliation. Survivor populations and defoliation rates on red spruce were similar in the three plots.

The density of the survivor population at L6 was critical to the accumulative defoliation for the season. Shoot attack and destruction rates stayed low and stable until mid June or L6 (Figs. 7 and 8). Similar defoliation rates were reported by Blais (1979) at similar levels of population. However, he noted that such high levels of defoliation had also occurred earlier in the season in stands where population density was very high. This suggests that at the population levels encountered in this study the spray period could be extended beyond the conventional period bracketting peak L3 to peak L4, if prospectively sufficient L5 and L6 could be killed at authorized spray dosages. However, at still higher population densities of L3 and L4, it would be unwise to delay spraying. Blais (1979) has shown that levels of 92 and 120 larvae per 45-cm branch tip (ca. 700-800/m²) cause 40-70% defoliation by the peak L4. For fir, the defoliation estimates given by the percent needles removed conformed with the shoot attack and shoot destruction rates for the three plots (Figs. 7 and 8). All defoliation measures were highest in the near-field drift plot followed by the spray plot and the far-field drift plot. In general, the survivor population (L6) at 90 larvae/m² produced 60-80% defoliation, an unacceptable rate of damage.

On spruce, all three measures of damage showed similar low rates around 10-30%, conforming to the almost equal larval densities in the three plots. The survivor density around 60 larvae/m² at peak L6 effected only light damage to the new foliage crop.

CONCLUSIONS

This study is a detailed account of larval population trends in three plots exposed to two applications of fenitrothion emulsion at varying deposit concentrations through the mechanism of swath drift, from the target block to downwind stands at 400 and 1200 m off-target. Budworm response was measured by tallies of surviving populations in the midcrowns of fir and spruce, and by mortality as indicated through collections from drop trays. The documentation of survival was fraught with sampling problems and was considered unreliable as an index of spray efficacy, especially in the populations on spruce. The evidence of within-crown redistribution of populations from chemical and natural stimuli casts doubt on the suitability of midcrown sampling, despite its advantages for economy of effort.

As expected, higher levels of deposit resulted in higher rates of mortality (drop-tray collections), but there are qualifications to this generality.

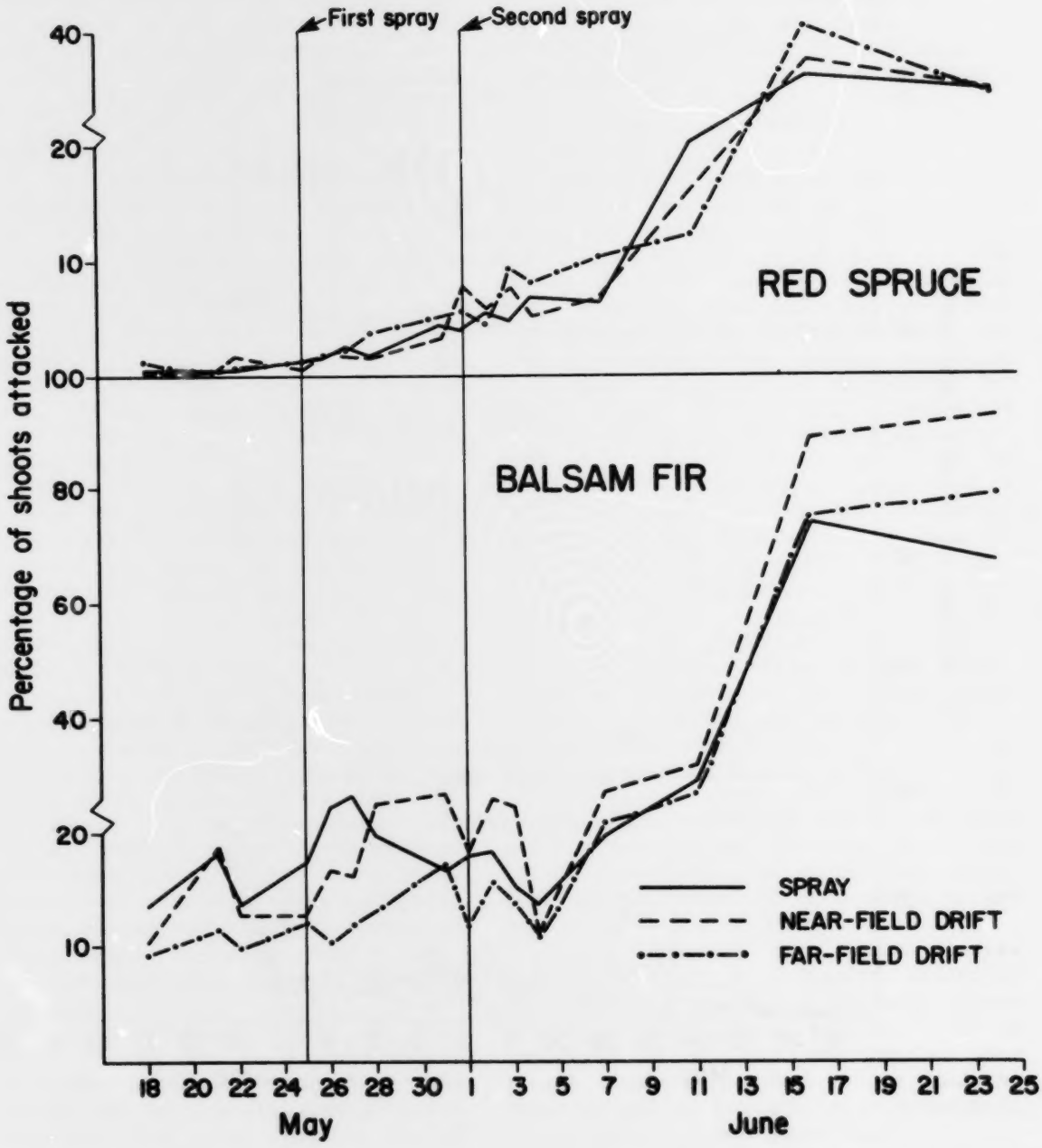


Fig. 7. Shoot attack rates on balsam fir and red spruce.

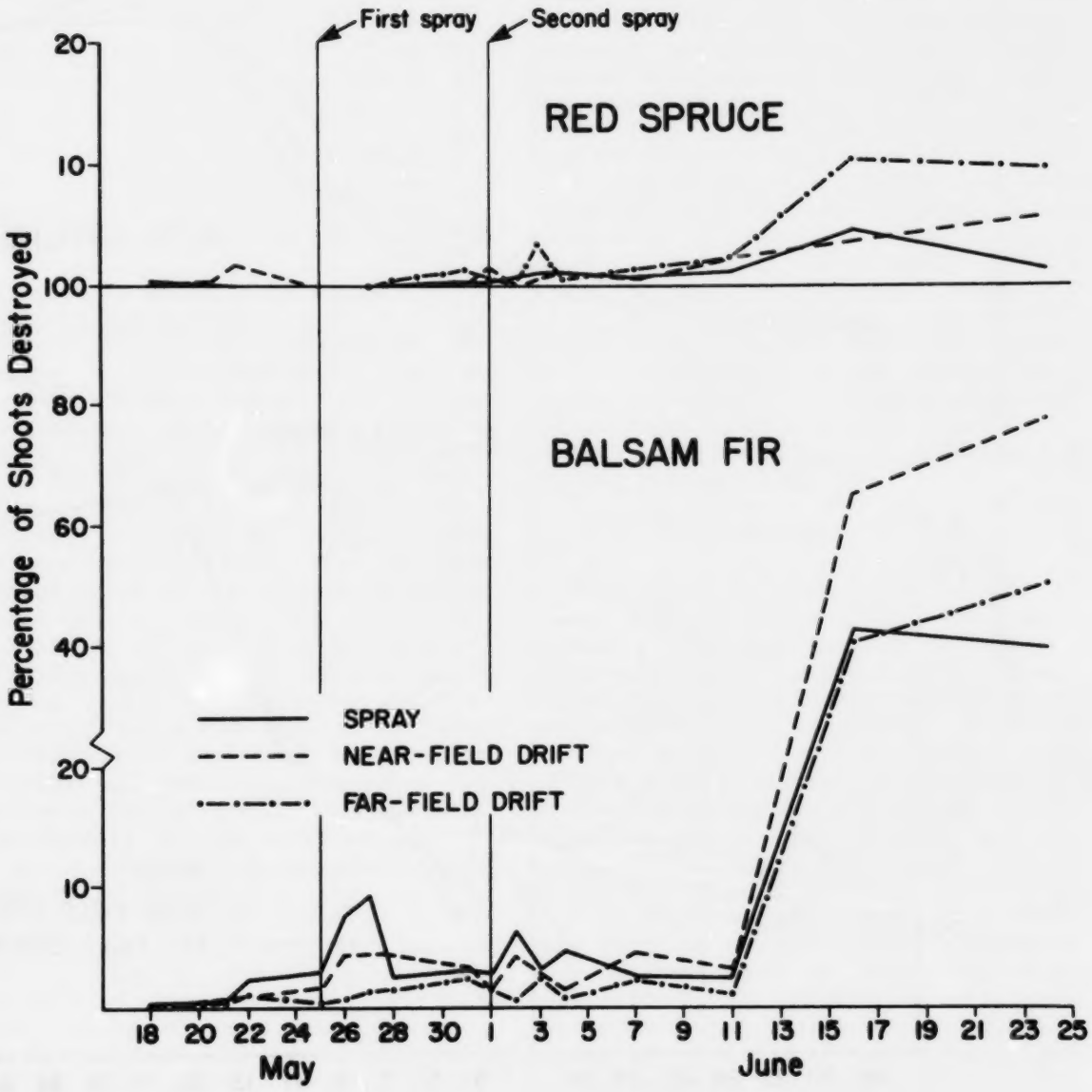


Fig. 8. Shoot destruction rates on balsam fir and red spruce. Defoliations estimated by the Fettes Method were fir plots: spray 62%, near-field 80%, far-field 71%; spruce plots: spray 9%, near-field 6%, far-field 18%.

Whereas in the earlier spray application, populations on fir and spruce suffered similar rates of mortality despite their disparate instar distributions and habitats, in the later spray the rate of mortality on fir was far higher than on spruce. Evidently instar distribution and/or bud phenology have substantial influence on efficacy, although the mechanisms of vulnerability are not well understood. Moreover this research design did not include an examination of droplet size spectrum and distribution patterns in the stands, so that a full understanding of efficacy in relation to drift was not attainable.

Observation and drop-tray data indicate that a small proportion of the budworm population dies from direct impingement of droplets. Rather, the larva must move to deposits on foliage; or alternatively, deposits must redistribute themselves to the budworm's sheltered feeding tube or mine. The fact that mortality is pulsed to the warm hours of successive days supports the hypothesis that weather-related behavior of the larvae is the principal mode of contact between the pest and the residues at the site of impaction.

It is concluded that several factors determine spray efficacy:

(1) Droplet deposition homogeneity

The distribution of droplets on foliage must be homogeneous across successive subdivisions of the target canopy (i.e., the outer shell of new foliage where the budworm lives) - across the swath, among individual trees, among downwind and upwind orientations, among elevational zones of the crown, among adjacent branches, and within single branches at the shoot level. Generally only a fraction of the available sites is occupied as a habitat.

This study documented only the distribution of deposits in a small sample of midcrown branches; thus both the macroscale and microscale distributions are unknown. The data obtained by GC analysis suggest that in these two operational applications, deposition at the branch level was heterogeneous within the spray plot with fenitrothion concentrations on individual branches varying in the range of 0.27 µg/g to 4.15 µg/g of foliage. With such a range, it is important to determine whether there is an associated variation in efficacy. Since homogeneity of deposit coverage at the budworm habitat is the goal, future studies should include the analysis of droplet distributions at the individual shoot level.

(2) Lethal concentration at the habitat

The deposits on each shoot must be distributed in such a way that the probability of lethal contact is high. A given quantity of insecticide may be expressed as a few big drops or many small ones. For high efficacy, the total quantity on a shoot should be distributed as droplets big enough that each unit could be toxic to one larva, but small enough that a high density of coverage be attained. Moveover the quantity deposited on a habitat must be sufficiently in excess on spray day to allow for rapid degradation yet still maintain toxic capability up to the third on fourth day. Joyce (1981) reasoned that the optimal droplet size would provide only a sublethal dose, and that contacts with several droplets would be required before a pest insect would be killed. He recognized that, subject to limits of impaction efficiency, smaller (sublethal) droplets can be distributed with far better coverage of prospective target foliage, and with a higher probability of cumulative lethality, than larger droplets each with lethal capability. We cannot yet define that optimal quantity as x droplets per needle, at y mean diameter.

It is desirable that future studies should incorporate a droplet distribution analysis at defined surfaces appropriate to the larval habitat. It is important to document the droplet size ranges reaching the real target, and the coverage needed for effective treatment.

(3) Behavior and phenology

Evidently there are stimuli that induce the larva to leave the sheltered mine or the inner tube where it spends most of its time, and to crawl on outer surfaces

of the habitat reached by droplets. These behavioral patterns and stimuli are not well known and have not been detailed in the literature. This study produces evidence that larval instar and bud development are implicated in vulnerability, but does not explain how. It suggests the hypothesis that temperature (warm weather) stimulates activities in the outer habitat; the principal activity observed is silk spinning, and that activity by L3 and L4 may be more restrained on red spruce than on balsam fir. There is the converse hypothesis that cold or wet weather may depress activity in the outer habitat because the larva is torpid in its inner habitat. Torpidity should reduce vulnerability. Future studies should attempt to identify these activities and stimuli.

The drift aspect of the study produced evidence that it is possible for droplets to be broadly distributed at fairly even density across a swath as wide as 400 m. The use of drop trays is a sensitive way to relate efficacy to drift deposit; in future studies the method could be applied to research on broad swathing in collaboration with scientists documenting the physical and meteorological transport of the spray cloud. Further, the evidence that the effective spray window open to operations might be expanded to include late L2 and late L5 (an extension around 2 weeks) encourages further research on spray timing. The combinations of wider swaths and more frequent applications within the regulatory limit of 420 g/ha of fenitrothion are tactical variations that merit research with respect to cost-effectiveness.

The twin criteria of spray efficacy are percent larval mortality and percent foliage saved. The current tactical goal is to retain at least 50% of the new foliage in a stand with a high hazard index. In severely infested stands the conventional success in killing larvae by split applications (70-80% mortality) may be inadequate to attain the foliage retention goal. Thus it may be necessary to devise a sliding scale of efficacy whereby the operational demand or spray frequency climbs with the hazard index.

To a large extent, the experiment was an exercise in available methodologies. Those methodologies are hardly adequate for the task, given a low-precision sampling effort.

ACKNOWLEDGMENTS

Field sampling and laboratory examinations were ably organized by Mr. G.N. Gesner, Maritimes Forest Research Centre. The work crews were undergraduates in summer jobs funded partly by Forest Protection Ltd. and partly by the Canadian Forestry Service. The courtesy and help of Forest Protection Ltd's. operational staff re spray application are acknowledged and appreciated. Insecticide analysis was conducted by New Brunswick Research and Productivity Council, Frederiction, under contract with the Canadian Forestry Service.

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APPENDIX I
SUMMARY OF WEATHER CONDITIONS
at Block 95/295, Magundy, York Co., N.B.

Date	Temperature Max.	Min.	Day degrees (Base 5.56°C)	Weather conditions	Hours of sunshine	
May						
17	14	-1	162	Rain	1.4	
18	9	-3	163	Sunny-cool	10.1	
19	13	-1	165	Cloudy & sunny intervals	5.6	
20	15	2	169	Cloudy & sunny intervals	6.2	
21	22	7	178	Sunny	10.3	
22	17	6	184	Cloudy & sunny intervals	4.1	
23	11	7	187	Rain	0.0	
24	22	8	196	Cloudy & sunny intervals	4.3	
First application of spray May 25						
25	27	-1	205	Sunny	11.1	
26	26	11	218	Cloudy, showers & sunny intervals	4.6	
27	27	13	232	Cloudy, showers & sunny intervals	3.8	warm and
28	25	14	246	Cloudy & humid	1.5	cloudy
29	24	15	260	Cloudy, showers & humid	1.3	
30	20	14	271	Cloudy, heavy rain overnight	1.5	
31	16	8	277	Rain	0.0	
Second application of spray June 1						
June						
1	20	2	283	Sunny	13.9	
2	22	0	290	Sunny	10.2	
3	25	10	302	Sunny	10.5	
4	24	13	315	Cloudy, showers & sunny intervals	4.0	
5	29	9	328	Sunny	9.4	fairly
6	20	14	339	Cloudy, sunny intervals & showers	4.6	warm, mostly
7	17	8	346	Rain, cleared P.M.	4.6	sunny
8	21	1	352	Sunny		
9	13	10	358	Rain	0.0	
10	17	8	365	Cloudy, windy	3.6	
11	22	2	372	Sunny (showers)	10.2	
12	22	7	381	Sunny (showers)	9.5	

APPENDIX II
GC analysis (fenitrothion) of branch tip units

	Spray		Near-field		Far-field	
	Foliage[1]	Fen[2]	Foliage	Fen	Foliage	Fen
	g	ug/g	g	ug/g	g	ug/g
Balsam fir deposits						
First application May 25						
Tree No. 1	60	1.38	61	0.01	56	0.03
2	70	1.67	76	0.04	52	0.04
3	78	1.00	75	0.04	66	0.03
4	55	1.38	43	0.10	38	ND[3]
5	55	1.22	56	0.10	52	0.03
6	64	1.43	28	0.03	53	ND
7	77	1.22	59	0.05	59	0.06
8	67	1.18	51	ND	81	ND
9	90	2.23	58	ND	62	0.60
10	78	1.43	60	ND	32	0.03
Mean		1.41		0.04		0.08
Second application June 1						
Tree No. 1	34	4.15	71	1.10	52	1.30
2	44	1.33	57	0.69	67	0.58
3	36	0.54	50	2.45	50	1.20
4	58	0.32	39	1.40	40	1.30
5	61	0.42	58	1.30	53	0.03
6	57	0.79	48	0.86	61	0.24
7	46	0.90	47	0.60	46	0.10
8	51	0.52	75	0.79	48	0.44
9	53	1.43	56	1.00	70	0.07
10	49	1.08	49	2.28	59	0.20
Mean		1.15		1.25		0.55
Red spruce deposits						
First application May 25						
Tree No. 1	54	0.58	44	0.05	25	0.08
2	74	0.63	39	ND	44	0.08
3	68	1.80	61	ND	46	ND
4	43	2.70	46	0.05	40	ND
5	62	2.60	17	ND	67	ND
6	52	2.90	59	ND	45	0.05
7	95	2.60	41	ND	51	0.18
8	71	1.30	36	ND	49	0.13
9	54	1.10	40	ND	40	ND
10	81	1.50	48	0.10	33	ND
Mean		1.77		0.02		0.05

APPENDIX II

GC analysis (fenitrothion) of branch tip units (continued)

	Spray		Near-field		Far-field	
	Foliage[1]	Fen[2]	Foliage	Fen	Foliage	Fen
	g	ug/g	g	ug/g	g	ug/g
Red spruce deposits						
Second application June 1						
Tree No. 1	56	1.85	59	0.97	48	0.90
2	43	0.70	51	1.60	40	3.90
3	42	0.59	49	1.10	56	0.20
4	38	0.60	37	1.29	39	1.90
5	28	0.65	38	1.74	27	0.20
6	39	0.80	40	0.85	33	0.20
7	47	0.27	61	0.85	59	0.50
8	34	0.88	45	1.20	49	0.20
9	34	0.38	47	2.50	43	0.30
10	55	2.28	62	1.30	49	0.50
Mean		0.90		1.34		0.88
Postspray-day residues						
Fir samples						
May 27	48	0.45	48	ND	-	-
June 3	47	0.22	48	0.18	52	0.15
June 5	120	0.18	100	0.12	66	0.12
Spruce samples						
May 27	44	0.13	44	ND	-	-
June 3	36	0.33	37	0.25	55	0.09
June 5	71	0.09	58	0.09	42	ND

Notes: [1]Foliage is weight of fresh foliage in grams.
[2]Fen is concentration of fenitrothion residues in micrograms per gram of foliage.
[3]ND is none detected. The date is the date of collection of the samples.
[4]To obtain degradation rate, the values for May 27 should be compared with the mean values for May 25, and the values for June 3 and June 5 should be compared with mean values for June 1.